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Influence of different phosphorus diets on bone parameters of growing pigs

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ABSTRACT

The objectives of this study were to examine the response of growing pigs to a level of phosphorus in excess of current usage and also to examine the effect of reducing phosphorus level in the later growing stages on bone characteristics. After slaughter, third metacarpals were removed from the front right foot of experimental pigs and the bones were weighed. Overall length of each bone and the width of bone shaft at the narrow and wide dimension were measured. Wall thickness, shear force resistance and ash percentage were also measured. Dry weight of bone was significantly affected by treatment ($P<0.05$). There was a similar trend for both bone ash weight and ash percentage, with those fed a phase phosphorus diet (low phosphorus level in the later growing stages) having significantly lower values than the other treatments ($P<0.01$). There was a trend for increased stress as dietary phosphorus level increased. We can conclude that pig bone development was significantly affected by dietary phosphorus level. The low-phosphorus diet gave significantly poorer results than the adequate-phosphorus diet; while there were no beneficial effects of supplementing phosphorus at a level higher than 2.4 g/kg. Lowering the phosphorus level to 1.6 g/kg in the late finishing stage seemed to produce a deleterious effect.

Key words: pig, bone, phosphorus, minerals

Introduction

All animals require adequate amounts of phosphorus because it is such an important element in body metabolism, accounting for over 25% of total body mineral matter, second only to calcium. Eighty per cent of phosphorus is found in the skeleton, deposited in bones with calcium, as the mineral hydroxyapatite CROMWELL et al. (1996). Twenty percent is located in the soft tissues, where it is involved in almost all biochemical reactions. A

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deficiency of phosphorus results in a depression in growth of body tissues, with bone becoming soft and fragile. Phosphorus from skeletal tissue is drawn upon first to maintain homeostasis. Therefore, the first symptoms of imbalances are aberrations of the skeleton KORNEGAY (1985).

Adequate dietary phosphorus can be defined in one of two ways, depending on whether maximum bone development or maximum growth rate and performance are required. Adequate levels of phosphorus for maximum pig performance are lower than for maximum bone development. Maximum bone development is important for longevity of the animal and this higher level of dietary phosphorus, required for maximum bone development, may have an effect on breeding pig performance. However, feeding higher dietary phosphorus levels would increase the amount of phosphorous excreted by the animal, and excess phosphorus in pig manure is a potential environment problem. It has also been proposed that lowering the dietary phosphorus levels in the late pig finishing stages would be beneficial by reducing the amount of phosphorus excreted, without having any detrimental effect on performance or carcass traits.

Bone mass, mineralisation measurements and mechanical characteristics are considered extremely accurate indicators of phosphorus status. These include bone strength (stress), bending moment, bone ash weight, and bone ash percentage. When compared to plasma alkaline phosphatase activity, these measurements were considered most sensitive KOCH et al. (1985).

Materials and methods

Animals and housing. The trial was carried out on a commercial pig farm. Three groups of six pigs were assembled. Pigs were selected at about 30-35 kg live-weight, weighed individually and randomly assigned to single six groups of three of even weight. One pen of each sex was randomly assigned to one of the following three treatments:

Diet 1. High phosphorus diet (3.0 g/kg digestible phosphorus; 5.9 g/kg total phosphorus).

Diet 2. Medium phosphorus diet (2.4 g/kg digestible phosphorus; 5.3 g/kg total phosphorus).

Phase fed phosphorus Diet 2 - 2.4 g/kg digestible, (5.3 g/kg total) phosphorus to 60 kg live-weight followed by

Diet 3 - 1.6 g/kg digestible, (4.3 g/kg total) phosphorus to slaughter.

Different phosphorus levels were achieved by varying the level of dicalcium phosphate in the diets. The BESTMIX 5.02 feed formulation programmer calculated digestible phosphorus levels.

Pigs were housed in fully slatted pens (concrete slats, 75 mm solid with 20 mm slots), 1.2 x 1.4 m with steel rail partitions. Pigs were fed from a Hyundai FIRE computerized feeder with dry pelleted feed ad libitum. Water was available from one drinking bowl per group.

Temperature control was by a ceiling mounted exhaust fan controlled by a Stienen temperature controller with temperature regulated at 20-22 °C. Air entry was from a service passage, via three manually adjusted inlets on the wall at the side of the room, opposite the fan.

Pigs were observed closely at least twice daily. Any pigs showing signs of ill health were treated as appropriate. Feeders and drinkers were checked daily and cleaned or adjusted as required.

Feeding and management. Pigs were fed ad libitum with care being taken to avoid feed wastage. Feeders were allowed to empty at least once weekly to avoid a build up of stale feed. Feed for the group was recorded at the time of feeding onto standard record sheets.

Feeder accuracy was checked each week (Mondays) by removing approximately 1.0 kg feed from the trough. Feed removed was weighed and checked against the weight recorded on the computer.

Slaughter. Pigs were slaughtered when average live weight exceeded 103 kg (on a Monday). Pigs were slaughtered in uneven groups over a two-day period.

Feed manufacture. Feed was manufactured in 1-tonne batches, conditioned by steam healing to 50 °C before pelleting into 5-mm pellets. Cereals were ground through a 3-mm

Table 1. Composition of experimental feeds, kg/tonne

	Diet 1	Diet 2	Diet 3
Barley	350	350	350
Wheat	409.25	410.75	412.75
Soya Hi-Pro	215.0	215.0	215.0
Lysine Synthetic	2.5	2.5	2.5
Methionine Synthetic	0.75	0.75	0.75
Threonine	1.0	1.0	1.0
Di Cal Phos	8.5	5.5	0
Limestone Flour	8.5	10	13.5
Salt	3.0	3.0	3.0
Vit-Mins	1.5	1.5	1.5
Total	1000	1000	1000

Table 2. Calculated analysis of feeds, g/kg

	Diet 1	Diet 2	Diet 3
Crude Protein	188	189	189
Lysine	11.1	11.1	11.1
Methionine	3.5	3.5	3.5
Meth+Cyst	6.9	6.9	6.9
Threonine	7.6	7.6	7.6
Tryptophan	2.3	2.3	2.3
Isoleucine	8.4	8.4	8.4
Leucine	13.7	13.7	13.7
Phenil+Tyros	14.8	14.8	14.8
Valine	9.2	9.2	9.2
Lysine digestible	9.8	9.8	9.8
Methionine dig.	3.2	3.2	3.2
Meth+Cyst dig.	6.1	6.1	6.1
Threonine dig.	6.5	6.5	6.5
Tryptophan dig.	1.9	1.9	1.9
Dry Matter	866	866	866
Energy DE MJ/kg	13.4	13.4	13.4
Energy NE MJ/kg	9.5	9.6	9.6
Fat	18.0	18.5	18.6
Linoleic	8	8	8
Crude fibre	35	35	35
Ash	46	45	43
Calcium	6.0	6.0	6.1
Total phosphorus	5.9	5.3	4.3
Digestible phosphorus	3.0	2.4	1.6
Potassium	7.4	7.4	7.5
Sodium	1.5	1.5	1.5
Starch+Sugar	458	459	461

screen before mixing. The vitamin-trace mineral mix was premixed through 5 kg cereal before addition to the mixer. Feed was then stored in pre-weighed 40 kg sacks, which were stamped with an ID number and date of manufacture and closed by sewing. Batches of feed were fed in order of date of manufacture.

Composition and calculated nutrient content of the diets is shown in Tables 1 and 2.

Bone parameters. Immediately after slaughter, third metacarpals were removed from the front right foot of all experimental pigs and frozen at -20 ^{o}C in airtight containers. Bones were later thawed and extraneous tissue removed. The bones were then weighed and the overall length of each bone and the width of bone shaft at the narrow and wide dimensions were measured (Fig. 1)

Bones were cut in half at the midpoint using a fine saw (junior hacksaw). Wall thickness at the mid-point of the narrow, wide and perpendicular dimensions was measured using a dial calliper and averaged to determine a value for wall thickness at the mid-point of the overall bone length (Fig. 1).

After bone measurements were taken, the marrow was removed and the bone was again weighed. The bone was dried in a crucible for 16 hours in an oven at 103 °C. Bones were

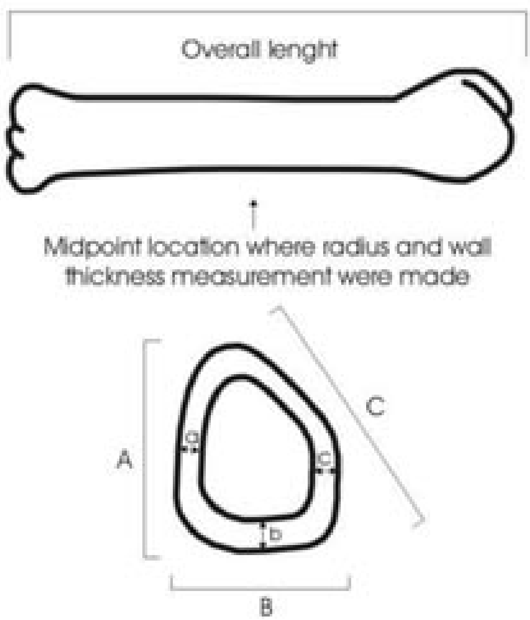

Fig. 1. A = wide dimension; a, b, c = locations of wall ; B = narrow dimension; thickness measurements; C = perpendicular dimension; radius = A+B/2 = r; wall thickness = a+b+c/3

re-weighed on removal from the oven after cooling and ashed at 600 °C until a consistent white ash was obtained (c. 48 hours). The crucible and its contents were weighed after cooling.

Bone strength was determined using a Hounsfield tensiometer based on the method by COMBS et al. (1991). Force was applied at a rate of 10 mm/min. The maximum force required to cause shear failure was recorded.

Measurements and analysis. Representative samples of the diets were taken in the feed mill at manufacture. All samples were ground using a Christy Laboratory Mill using a 2-mm screen and stored in plastic containers at -20 °C pending analysis. Feed samples were analysed for dry matter, crude fibre, crude protein, ash, oil, pellet durability, total Ca and total P.

Table 3. Analysed chemical composition of experimental diets, g/kg

Diet No.	1	2	3
Dry matter	860	856	856
Ash	43	39	39
Oil	18	18	19
Crude Fibre	35	37	33
Crude Protein	172	166	178
Total P	6.3	5.35	4.45
Pellet Durability	972	970	970

Dry matter was determined by drying in an oven at 103 °C for 4 hours and ash by incineration in a muffle furnace at 550 °C for 16 hours. Crude protein was determined as Nx6.25 using a LEGO FP 2000. Crude fibre was measured by a Tecator semi-automatic instrument, and oil by extraction with perchlorethlene in a Foss Let 15300. Pellet durability was determined using a Holmen Pellet Tester.

Statistical analysis. Statistical analysis was by the methods of SAS Inc, Gary, N. Carolina, for a randomized complete block design.

Results

Chemical composition of diets. Chemical composition of diets fed in this experiment is shown in Table 3. The ash content of diets 2 and 3 was lower than expected. Crude protein was also lower. All other components were similar to expected values.

Pig health. In general, the health of the pigs in this experiment was good. Just one pig was removed from the trial.

Bone parameters. Treatment had no effect on any bone dimensions measured (Table 4) (P>0.10). Fresh bone weight was also unaffected. However, the weight of the empty bone tended to be lower on diet 1 changed to 3 at 60 kg live weight compared to the other diets (P = 0.08). Dry weight of the bone was significantly affected by treatment (P<0.05), with the group fed diet 1 changed to 3 having the lightest bone dry weights. There was a similar trend for both bone ash weight and ash percentage, with those fed 1 and then changed to 3 at 60 kg having significantly lower values than the other treatments (P<0.01). There were no differences between treatment 1 and 2 for bone characteristics. Bone stress was not significantly affected by treatment (P = 0.47). However, there was a trend for increased stress as dietary phosphorus level increased.

Table 4. Effects of treatment on bone dimensions, weight and bone strength

Diet	1	2	1 changed to 3 at 60 kg	Simple effect	P-value[1]
g/kg digestible P	3.0	2.4	2.4/1.6		
Bone length (mm)	76.8	76.8	75.9	0.78	0.65
Wide dimension (A) in mm	16.2	16.3	16.2	0.20	0.83
Narrow dimension (B) in mm	13.8	13.6	14.0	0.29	0.61
Perpendicular dimension (C)	18.5	18.6	18.2	0.25	0.36
Wall thickness (A) in mm	1.42	1.36	1.31	0.051	0.286
Wall thickness (B) in mm	2.47	2.41	2.27	0.090	0.299
Wall thickness (C) in mm	1.33	1.28	1.25	0.039	0.355
Fresh weight (g)	25.6	25.8	24.1	0.73	0.20
Empty bone weight (g)	22.7	23.0	21.2	0.60	0.08+
Dry weight (g)	15.8	16.0	14.4	0.38	<0.05*
Ash weight (g)	7.34	7.35	6.34	0.170	<0.01**
Ash in bone (g/kg)	466	461	440	4.9	<0.01**
Bone stress (force in N)	3817	3757	3430	243.33	0.47

[1] +P<0.10; *P<0.05; **P<0.01

Discussion

In our experiment, treatment was found to have no significant effect on bone dimensions. These findings are supported by BOSI et al. (1997) who found no effect of phosphorus level on bone measurements. Conversely, CRENSHAW et al. (1981) found that increased P in diet increased wall thickness.

Empty bone weight tended to be affected by treatment, although not significantly ($P = 0.08$), while dry weight and ash weight were both significantly affected by diet ($P<0.01$). There were very small differences in weights between diet 1 and diet 2, with no increases as the dietary phosphorus level increased. The low-phosphorus diet resulted in lower dry weights and ash weights. This is in agreement with KORNEGAY and THOMAS (1981), who reported no increase in weight when phosphorus was supplemented above requirements. However, there was a decrease in weights as the phosphorus level was decreased, which agreed with our results. Conversely, KETAREN et al. (1993) reported an increase in bone dry weight with increasing dietary phosphorus up to an available phosphorus level of 4 g/kg.

Bone ash percentage was also significantly affected by treatment ($P<0.01$), showing an increase as phosphorus level increased. CRENSHAW et al. (1981) agrees with this, reporting similar results in their experiments. KORNEGAY and THOMAS (1981) show a reduction in bone ash percentage in low-phosphorus diets, while in high-phosphorus diets there was no difference found in ash percentage. KETAREN et al. (1993) reported a curvilinear response in bone ash concentration as phosphorus level increased. Similarly, O'QUINN et al. (1997) found that ash concentration increased as phosphorus level in the diet increased. However, BOSI et al. (1997) found no changes in total ash concentration of bones.

Bone stress (force measured in N) in this experiment was not significantly affected by treatment, although there was a trend for increased bone strength with increasing dietary phosphorus intake. Pigs on the low phosphorus diet (diet 1 to 3) had considerably lower stress values than the high phosphorus diet (diet 1). Reports in the literature, however, have shown that dietary phosphorus levels have a significant effect on bone strength values. CRENSHAW et al. (1981) compared a high level and a low level of dietary phosphorus (0.8 and 0.4%). They found that bone-bending moment was greatest on the high phosphorus diet with bones from the low phosphorus diet unable to withstand as much stress as bones from the high phosphorus diet. COMBS et al. (1991) found similar results when he compared calcium/phosphorus levels at 70, 85, 100, 115, and 130% of estimated requirements. Bone shear stress increased at a decreasing rate in response to increasing dietary calcium/phosphorus intake. These results agree with VAN KEMPEN et al. (1976), who compared four dietary phosphorus levels (0.4, 0.5, 0.6, and 0.7% total phosphorus). They found that bone strength increased significantly with increasing phosphorus level, but at a decreasing rate. These results are confirmed by other researchers NIMMO et al. (1981), DERODAS et al. (1996), and O'QUINN et al. (1997).

In contrast, KORNEGAY et al. (1981) compared different dietary calcium/phosphorus levels (75%, 100% and 125% of estimated requirements), finding that at the low phosphorus level, bone breaking strength was significantly reduced. However, breaking strength was not consistently increased when 125% phosphorus was fed. Maximum bone strength was found to be at the level of 125% calcium and 125% phosphorus inclusion in the diet. GRANDHI et al. (1986) reported no effect of dietary phosphorus level on bone strength values. They compared two calcium/phosphorus levels (100% and 150% of estimated requirements) in gilts and sows and found no effect of dietary levels on bone strength. This may have been because the increased calcium/phosphorus levels were only fed for a short duration, whereas in the other trials diets were fed for a longer time.

Conclusions

From our experiment we can conclude that:

Pig performance was significantly affected by dietary phosphorus level.

The low-phosphorus diet (2.4 g/kg changed to 1.6 g/kg digestible phosphorus) gave significantly poorer results than the adequate-phosphorus diet (diet 2.4 g/kg).

There were no beneficial effects of supplementing phosphorus at a level higher than 2.4 g/kg.

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SAŽETAK

Istražen je utjecaj prekomjernog dodavanja i smanjivanja količine fosfora na značajke kostiju u kasnijoj fazi rasta svinja. Nakon klanja svinjama je s prednje desne noge uzeta treća metakarpalna kost te je svakoj uzetoj kosti izmjerena masa, dužina i obujam na najužem i najširem dijelu. Također je mjerena debljina kompaktne supstancije, jačina otpornosti i udio pepela. Dodavanje fosfora u hrani znatno je utjecalo na suhu tvar kostiju (P<0,05). Slično je ustanovljeno za sadržaj pepela i njegov udio za vrijeme dodavanja fosfora (niska razina fosfora u kasnijoj fazi rasta) pri čemu su ustanovljene signifikantno niže vrijednosti u odnosu na druge tretmane (P<0,01). Ustanovljena je i povećana sklonost stresu ovisno o povećanju fosfora u obroku. Zaključuje se da je na razvoj kostiju u svinja značajno utjecala količina fosfora u obroku. Niska razina fosfora u obroku dovela je do znatno lošijih rezultata u odnosu na obrok s primjerenom količinom fosfora, iako nije bilo povoljnog učinka kad je fosfor dodan u količini većoj od 2,4 g/kg. Smanjenje količine fosfora na 1,6 g/kg u završnoj fazi rasta imalo je štetan učinak.

Ključne riječi: svinja, kost, fosfor, minerali